HOW OLD ARE FOSSILS?

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LIST OF GEOLOGICAL LEAFLETS ISSUED TO DATE

No.	1.	Model of an Arizona Gold Mine	$ .10
No.	2.	Models of Blast Furnaces for Smelting Iron .	.10
No.	3.	Amber—Its Physical Properties and Geological Occurrence	.10
No.	4.	Meteorites	.10
No.	5.	Soils	.10
No.	6.	The Moon	.10
No.	7.	Early Geological History of Chicago	.25
No.	8.	Agate	.50
No.	9.	How old are Fossils?	.25

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A VIEW OF THE GRAND CANYON OF THE COLORADO RIVER, ARIZONA.

ZOROASTER IN BACKGROUND.

Photograph by O. C. Farrington.

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How old are Fossils?

"How old is that fossil and how do you know it?" is a question frequently asked by visitors going through the hall of fossils in the Museum. A precise answer to such a question is impossible and an adequate one demands a longer time than can usually be afforded. The consequences of inadequate explanation have often proved to be unsatisfactory. The visitor becomes skeptical and instead of taking interest in the subject, he seems to be confirmed in his doubts.

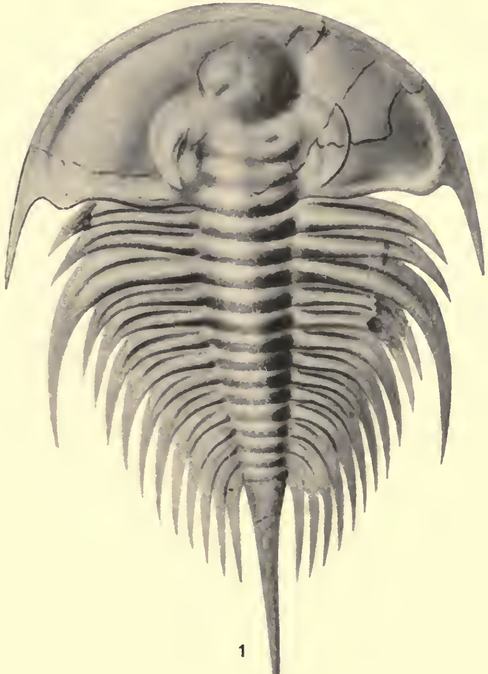
In this leaflet is given a condensed, general statement of methods of determining the age of ancient life. The information is drawn from the works of various authors, especially Barrell's "Rhythms and Measurements of Geologic Time." It is intended for those who are interested in the age of past life and yet do not intend an exhaustive study of the subject, nor have free and easy access to its literature.

The birth of life was the most momentous occasion in the history of the earth. When one considers the myriads of evidences unearthed by paleontologists and paleobotanists, they seem to leave no room to doubt the great conception that the life of the land has emerged from the sea. It is, therefore, only a natural impulse to look for the remains of this life in the rocks laid down by the ancient seas and to wonder at the vastness of time behind them.

Since traces of the lowest forms of life have been found in practically the oldest known sedimentary strata,

the problem of determining the age of life necessarily involves the determination of the age of those strata. But unravelling the dead past is not an easy task. One trying to unlock the "secrets of the cemetery of Nature's dead," walks on a shadowy road. His difficulties are many. It is like crossing a deep moat, climbing a steep wall.

Various methods have been applied to estimate the age of different periods of the earth's history and much progress has been made toward a successful issue. Broadly, the procedure of different methods is the same. They do not differ in principle. "The rates of certain changes at the present day are determined as accurately as possible, and in imagination, the respective processes are traced backward in time until limiting conditions are arrived at." Until the epoch-making discovery of radium, the two most outstanding methods used in calculating geologic time were (1) the rate of land erosion and deposition and (2) the rate of derivation of salt (sodium chloride) from the land and its accumulation in the oceans. Theoretically, it is simple to use the rate at which sediments are being deposited or solutions gathered into the ocean, as "geologic clocks" for estimating the length of past time. But in practice each method encounters its own difficulties and the results deduced give us at best only a rough idea of the immensity of time involved. I shall not deal with these individual estimates, but give the mean of several, which is 100,000,000 years, speaking roundly. As stated before, it is only a rough estimate. Nevertheless, it confirms the fact that the earth is very old—indeed much older than is commonly believed. In 1650, Bishop Ussher, in his interpretation of the "In the beginning" of Genesis, estimated that the earth was created 4004 years before the birth of Christ. According to this view the earth is 5931 years old today. Many cosmogonists and even some geologists of the 19th century held this Biblical interpretation to be the age of the earth. Other ancient religions held that the earth was created much earlier then 4004 B. C. Hutton,



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COMPARISON OF AN ANCIENT AND A MODERN MARINE ANIMAL OF ALLIED GROUPS.

1, A CAMBRIAN TRILOBITE (AFTER WALCOTT). 2, A MODERN HORSESHOE CRAB.

one of the founders of Geology, in his studies, found "no vestige of a beginning—no prospect of an end." One cannot help sympathizing with Hutton. Whoever has made a trip to the Grand Canyon of the Colorado River, Arizona, must remember the awe-inspiring depth of the Paleozoic strata and thousands of feet of Proterozoic sediments beneath them (Pl. I). If he has traveled farther north to the Cabinet Range, Montana, he must have carried with him an undying impression of the 35,000 ft. of the rocky monument, there built up by the Proterozoic seas.

The present rate of denudation in the Hudson Bay region is one foot in about 47,000 years. How long then, has it taken the seas to lay down these miles of sediments, which are but a small fraction of the whole geologic column? Having considered all this, can we estimate, even approximately, the vast length of time that has elapsed between these periods of sedimentation, the so-called "gaps" or "breaks"—the torn, illegibly written pages of the history of the earth? Indeed, there are moments when all may feel that it is much beyond their comprehension. But, man, by nature, is at once humble and exalted. He is willing to admit his defeat, yet his thirst to conquer new knowledge, to know the truth, is never satiated.

The reason for the failure to arrive at an absolute result is not very far to seek. In computing geologic time, one has to calculate that which has elapsed, by some process in nature that takes place in one direction only and that does not change its rate when conditions alter. Whatever the method applied, be it the deposition of sediments, or the gathering of solutions, or the losing of heat by the sun and the earth, its rate of action should be uniform and uninterrupted. It should be independent of the changing conditions of the earth. Uniformity of the rate of action is the criterion for precise calculation. But we know that the past was quite different from the present. Different conditions have existed at different times during the

earth's history. The configuration of the earth, its climate, humidity, temperature and many other factors have varied from time to time and with them the rate of erosion, deposition and solution has either accelerated, diminished or ceased. The doctrine of uniformitarianism cannot be assumed in a changing world, even though our knowledge of the earth of the past can only be gained from a fuller study of the earth of the present.

When we consider the rate of sedimentation as a method for estimating geologic time, we take the total observed thickness of the geologic column, (estimated to be 70 miles) and divide it by the rate at which the sediments are now being laid down. But do we know this rate? By taking the average rate of sedimentation of nine large, rivers* now in existence and assuming it to be the rate at which sediments were deposited in the past, an approximate conclusion can be arrived at. But it will be noticed from the figures of the rate of sedimentation of different rivers that they are widely variable, the highest being many times greater than the lowest. Can we then use an average of nine figures so out of proportion and yet expect a reliable quantitative value? Furthermore, the rate of deposition along the coast, near the mouth of a large and active river, is much higher than on a coastline where no

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River	Drainage areas in square miles	Total tons annually	Ratio of sediment to water in weight	Height in feet of column of sediment with a base of 1 square mile
Potomac	11,043	5,557,250	1:3,575	4.0
Mississippi	1,244,000	406,250,000	1:1,500	241.4
Rio Grande	30,000	3,830,000	1: 291	2.8
Uruguay	150,000	14,782,500	1:10,000	10.6
Rhone	34,800	36,000,000	1:1,775	31.1
Po	27,100	67,000,000	1: 900	59.0
Danube	320,300	108,000,000	1:2,800	93.2
Nile	1,100,000	54,000,000	1:2,050	38.8
Irrawaddy	125,000	291,430,000	1:1,610	209.0

Babb. Science, Vol. XXI, p. 343, 1893.

rivers empty their sediments into the sea. The rate is also largely controlled by the character of the sediments deposited. Sandstone and shale are more rapidly deposited than limestone. Moreover, just as there is no knowledge of the duration of time of erosion between periods of sedimentation, there is also no record of the amount of detritus that has fallen off the edge of the continental shelf during widespread emergence of the continents.

We have also no record of the vast quantity of shallow water sediments that were stirred up by the penetration of storm waves, and carried to abyssal depths by the currents and tides.

Similar uncertainties beset us when we consider the rate of chemical denudation, that is, the rate at which salts have been dissolved from the lands and accumulated in the oceans, as a measure of geological time. Here, again, we take the total amount of salts that is in the oceans today and divide it by the present rate of annual supply. We know with reasonable accuracy the quantity of salts in the oceans and if it were possible to assume the present rate of supply to be a true mean for all geological time, a satisfactory age of the oceans might be obtained. But it cannot be assumed as such. An assumption of this nature will only lead us from the domain of exactness to that of uncertainty. Aside from various other factors, neither the area of the continents, nor their relief was in the past the same as today. Consequently, the stream gradient and its power of dissolving salts from the land surfaces have not been the same. It is also not known how much salt the ocean derived from the shore line and from beds beneath the ocean, nor how much of the rock-salt beds on the earth that has been precipitated out of ocean water.

It is plain, therefore, that the rate of any process that is controlled by so many conditions cannot be used (even making generous allowances for irregularities and inaccessible data) as a reliable guide to evaluate geologic time. "It

is a clock," says Harker, "which now hurries and now creeps or stands still, and it cannot be trusted as a timekeeper."

Any estimate based on the temperature of the earth, or of the sun, encounters similar practical difficulties, for the temperature of a body may not be constant. It may rise or it may fall. Further, the rate of change of temperature is controlled by a variety of conditions, such as the amount of energy radiated, the supply of energy and so forth. Nor is there any record of the immense quantity of heat produced by igneous agencies and radio-activity.

Another estimate, one of the earliest, was based on the rate of life transformation in successive periods. The geological series were divided into twelve periods and it was believed that 20,000,000 years were required for an entire change in the species of each period, or 240,000,000 years in all. This does not include the time in which we have no record of plant or animal life.

There is no reasonable debate as to the passage of one species to another. It is clearly manifested in the succession of fauna found today all over the world in the sedimentary rocks. Even the most casual student of paleontology is convinced of this glaring truth. "The brutal cogency of a slab of fossils could be hated and fought, but could not be gainsaid." But when we are confronted with the question of setting a standard of measuring geologic time by means of this paleontological record, more precisely, through this biological process, we cannot help pondering over the grave uncertainty of the result. When we fix our gaze upon a trilobite, a three-lobed, crab-like creature (Pl. II fig. 1) that ruled the seas in the dim days of the Cambrian period (p. 11) and see that it was equipped with gills and swimming organs, with powers of digestion and excretion, with specific organs of circulation and reproduction and with motor and sensory nerves, and compare it with one of its tribe, a present day horseshoe crab, (Pl. II fig. 2) we do

not find any noticeable progress in structure, in intricacy or in the degree of specialization. Yet the time that has elapsed since the Cambrian is, according to a moderate estimate, nearly 600,000,000 years! (p. 11). Geologic record testifies that evolution awaits environmental change, that animals in some way adjust themselves to their environment, either by discarding or modifying old characters or by acquiring new ones. Yet, what are known as "immortal" types, such as the brachiopods, Lingula, Crania and Terebratula (Pl. III figs. 1-3) or the pelecypods, such as Pecten, Pinna and Arca (Pl. III figs. 4-6) or the gastropods, such as Pleurotomaria, Natica and Trochus (Pl. III figs. 7-9), have withstood all possible environmental changes and have steadfastly held their own ever since we have records of their very early appearance on earth. On the contrary, we have records of types that have yielded so rapidly to change that their evolution is almost explosive. It is almost incomprehensible how, within such a limited period of time, fishes have changed into amphibians, amphibians into reptiles, and reptiles into birds and mammals (Pl. IV figs. 1-4). With these conflicting evidences staring us in the face, with the knowledge that the entire organic world has been subject to earth-wide periods of long stagnation and rapid intensive change, one may well ponder whether it is within our power to establish a standard for measuring geologic time on the evidence of life transformation. The study of the succession of faunas—the change of one species to another, can only indicate the magnitude of time involved. It cannot afford any basis, whatsoever, for a concrete expression of geologic time.

During the last three decades, a number of radioactive changes of one chemical element into another have been discovered and studies of certain minerals and rocks containing various radio-active elements have created means to calculate their age with remarkable accuracy. "A study of the various radio-active elements contained in

minerals and rocks," says Harker, "has shown that it is possible, in certain favorable cases, to calculate directly their age in years."

The radio-active minerals are commonly found in igneous rocks. They are widely distributed all over the world. The parents of the whole series of radio-active elements are uranium and thorium. They possess the highest atomic weights of all known elements. Each of these parental elements transforms itself through a succession of changes. The final product of uranium is the formation of the metal lead and the gas helium. These transformations take place in one direction only, that is, from an element of higher atomic weight to an element of lower atomic weight. It has also been demonstrated beyond question that these transformations are unalterable by any process whatsoever and that they are independent of temperature, pressure or any other physical or chemical state. Temperatures up to 2,500 C. and pressures up to 600 tons per square inch have not been found to influence the rate of transformation. Time estimated on the basis of these processes, therefore, offers a more reliable result than that obtained by any other method hitherto known. Detailed descriptions of how the metal uranium slowly and regularly breaks down in a descending series into the metal lead and the gas helium, will be found in the literature on radio-activity. For our purpose, it suffices to say that according, to Barrell, an atom of uranium which breaks up will ultimately give rise as a stable product to eight atoms of helium and one atom of lead. Since the rate of transformation is known, data for calculating the age of the mineral and with it the rock formation of which it is a part, can be obtained by measuring the quantity of helium and lead in the rock and comparing it with the quantity of uranium in the same volume of material. But, as helium is a gas, it is likely that a certain portion of it leaks out and consequently the estimate of age on the basis of how long helium had been in contact with uranium

and lead is to be regarded as a minimum estimate. For example, the age of the mineral thorianite that occurs abundantly in the sands and gravels of Ceylon has been estimated to be 280,000,000 years, but the mineral is doubtless much older, as, ever since it was broken away from its orginal home in the pegmatite dikes of Ceylon, it lay exposed to the action of weathering and it was, therefore, very likely that during all these years a certain percentage of its helium contents had leaked away.

But estimates based on the lead ratios of radio-active minerals offer results consistent among themselves. That is, whenever fresh, primary, uranium-bearing minerals of the same geological age have been examined, the lead ratios are always found to remain constant. The value of the ratios increases or decreases as the geological age of the respective mineral increases or decreases. In other words, the lead ratios are in keeping with the geological age.

The procedure of applying the lead ratio in calculating geological time can be briefly stated thus: The rate of production of lead from uranium can be readily calculated. The rate at which helium is generated is accurately known and the quantity of lead liberated in the same time is approximately 6.5 times that of helium. In a year one gram of uranium produces 1.25×10^{-10} grams of lead, and at this rate 8,000* million years will be required for the production of one gram of lead.

There is no serious difficulty in applying this method for measuring geologic time, except that it is necessary to determine whether the lead is of radio-active origin or original lead. The presence of original lead is likely to mar the constancy of the lead ratio essential for accurate results. But ordinary lead need not be confused with uranium lead, as the atomic weight of ordinary lead is 207.1 and that of uranium lead is 206.2. Values between

*A more recent and accurate computation reduces this 8,000 million years to 7,500 million years.

these two figures imply a mixture of two types of lead. For reliable calculations, a series of fresh, primary minerals of the same geological age showing a constant lead ratio of atomic weight 206.2 needs to be examined.

The following table shows the geologic time that has elapsed between the first evidences of life and the present, as calculated by Barrell from radio-active data. The figures are his minimum and maximum estimates. It will be noticed from the figures in the table that the earliest life of which we have fossil records is about 1,500,000,000 years old. From this, it could be safely concluded that the inception of life on earth must have taken place much earlier. It is quite significant that each geological era, occasionally a geological period, has its characteristic grouping of life developed from the life of preceding periods. As we climb higher in the geological column, life becomes more and more complex and specialized. From the one-celled life of the Archeozoic it passes through the invertebrates—fishes—amphibians—reptiles—birds and mammals to man of the Recent time.

Since Barrell's publication of the estimates of geologic time as measured by means of radio-activity, some further studies have been made along the same line, but, as no generally accepted results have shown any marked differences from Barrell's results, it has been deemed advisable to use his age data as perhaps our present most adequate guide as to the length of geologic periods.

Although the measurable forces of radio-activity give on the whole a remarkably satisfactory time gauge and are doubtless more accurate than any method here discussed, it must not be considered that the ages given (p. 11) are absolute. The knowledge of geological time is of more importance for the comparative than for the absolute magnitude of the results obtained. Just as the study of astronomy gives us the conception of the vastness of space, so does the study of geology reveal to us that of the immensity of time.

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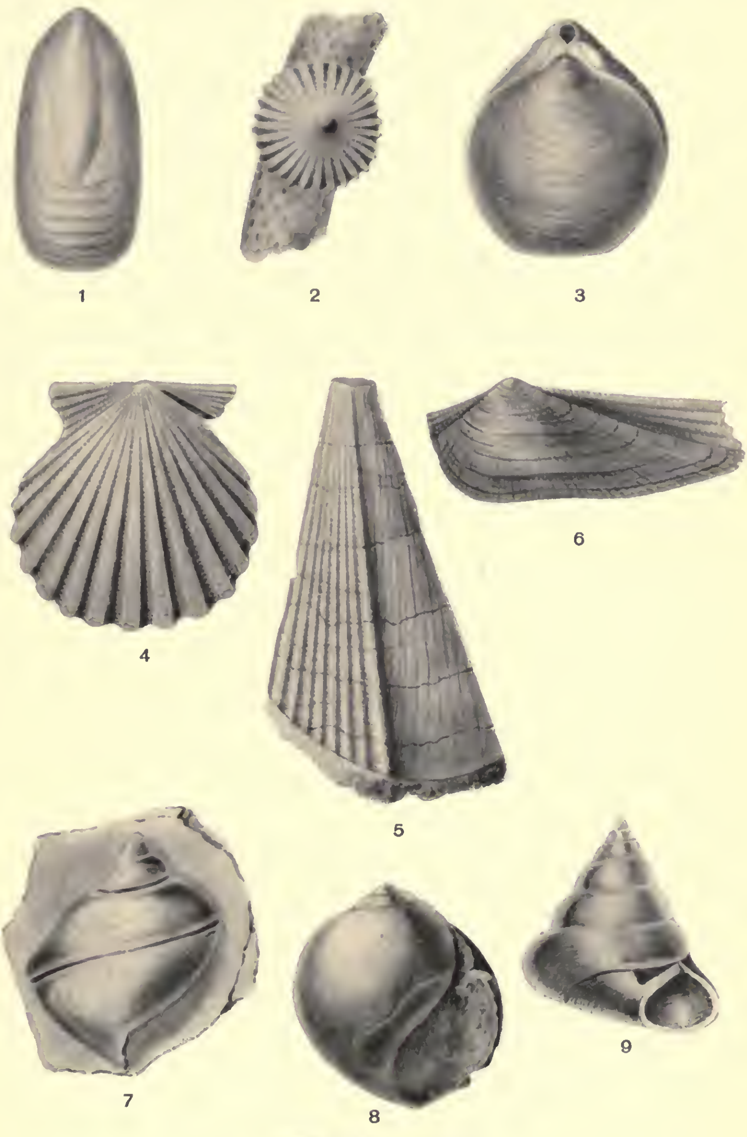

"IMMORTAL" TYPES.

1, LINGULA. 2, CRANIA. 3, TEREBRATULA. 4, PECTEN. 5, PINNA. 6, ARCA. 7, PLEUROTOMARIA. 8, NATICA. 9, TROCHUS.

(Figs. 1, 2, 7, after Hall, 3, 9, after Zittel, 4, 6, after Dall, 5, Pal. N. J. I, 8, after Cragin). Drawings by Carl F. Gronemann.

THE GEOLOGICAL TIME TABLE

1.0 = One million years

ERAS	PERIODS	TIME SCALE (After Barrell)		CHARACTERISTIC LIFE
		Minimum	Maximum	
PSYCHOZOIC	Recent	1	1.5	AGE OF MAN
CENOZOIC	Pleistocene			
	Pliocene	7	9	AGE OF MAMMALS AND MODERN FLOWERING PLANTS
	Miocene	19	23	
	Oligocene	35	39	
	Eocene	55	65	
MESOZOIC	Cretaceous	95	115	AGE OF REPTILES
	Comanchian	120	150	
	Jurassic	155	195	
	Triassic	190	240	
PALEOZOIC	Permian	215	280	AGE OF AMPHIBIANS AND ANCIENT FLORAS
	Pennsylvanian	250	330	
	Mississippian	300	370	AGE OF FISHES
	Devonian	350	420	
	Silurian	390	460	AGE OF HIGHER SHELLED INVERTEBRATES
	Ordovician	480	590	
	Cambrian	550	700	
PROTEROZOIC	Systematic classification variable	925		AGE OF PRIMITIVE INVERTEBRATES
		LONG EROSIONAL INTERVAL		
ARCHEOZOIC		1500		DAWN OF UNICELLULAR LIFE, ALGAL FORMS REPORTED

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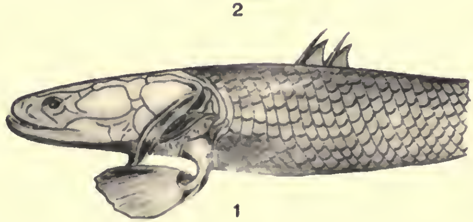

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EVOLUTION OF FISH TO MAMMAL-LIKE REPTILE.

1, FISH. 2, AMPHIBIAN. 3, REPTILE. 4, MAMMAL-LIKE REPTILE.
(Figs. 1, 2, after Klaatsch, 3, based on Williston, 4, based on Gregory).
Drawings by Sharat K. Roy.

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